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LEVEL II

TEST REPORT

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(6) THE STABILITY DERIVATIVES OF THE SCHEME A BODY USED WITH THE AN/SQA-13 (XN-1) VARIABLE DEPTH SONAR SYSTEM

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by

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NOTATION

Symbol	Dimensionless Form	Definition
B	$B' = \dfrac{B}{\frac{1}{2}\rho \ell^2 U^2}$	Buoyancy force
CB		Center of buoyancy of body
CG		Center of mass of body
I_x, I_y, I_z	$I_x' = \dfrac{I_x}{\frac{1}{2}\rho \ell^5}$	Moment of inertia of the body about x-, y-, and z-axis
K	$K' = \dfrac{K}{\frac{1}{2}\rho \ell^3 U^2}$	Hydrodynamic moment about x-axis through CG
ℓ	$\ell' = 1$	Characteristic length of body
M	$M' = \dfrac{M}{\frac{1}{2}\rho \ell^3 U^2}$	Hydrodynamic moment about y-axis through CG
M_q	$M_q' = \dfrac{M_q}{\frac{1}{2}\rho \ell^4 U}$	Derivative of moment component with respect to angular velocity component q
$M_{\dot{q}}$	$M_{\dot{q}}' = \dfrac{M_{\dot{q}}}{\frac{1}{2}\rho \ell^5}$	Derivative of moment component with respect to angular acceleration component $\dot{q}$
M_w	$M_w' = \dfrac{M_w}{\frac{1}{2}\rho \ell^3 U}$	Derivative of moment component with respect to velocity component w
$M_{\dot{w}}$	$M_{\dot{w}}' = \dfrac{M_{\dot{w}}}{\frac{1}{2}\rho \ell^4}$	Derivative of moment component with respect to acceleration component $\dot{w}$
M_θ	$M_\theta' = \dfrac{M_\theta}{\frac{1}{2}\rho \ell^3 U^2}$	Derivative of moment component with respect to pitch angle component θ
m	$m' = \dfrac{m}{\frac{1}{2}\rho \ell^3}$	Mass of body, including water in free-flooding spaces

Symbol	Dimensionless Form	Definition
N	$N' = \frac{N}{\frac{1}{2}\rho \ell^3 U^2}$	Hydrodynamic moment about z-axis through CG
N_r	$N_r' = \frac{N_r}{\frac{1}{2}\rho \ell^4 U}$	Derivative of moment component with respect to angular velocity component r
$N_{\dot{r}}$	$N_{\dot{r}}' = \frac{N_{\dot{r}}}{\frac{1}{2}\rho \ell^5}$	Derivative of moment component with respect to angular acceleration component $\dot{r}$
N_v	$N_v' = \frac{N_v}{\frac{1}{2}\rho \ell^3 U}$	Derivative of moment component with respect to velocity component v
$N_{\dot{v}}$	$N_{\dot{v}}' = \frac{N_{\dot{v}}}{\frac{1}{2}\rho \ell^4}$	Derivative of moment component with respect to acceleration component $\dot{v}$
q	$q' = \frac{q\ell}{U}$	Angular velocity component relative to y-axis
$\dot{q}$	$\dot{q}' = \frac{\dot{q}\ell^2}{U^2}$	Angular acceleration component relative to y-axis
r	$r' = \frac{r\ell}{U}$	Angular velocity component relative to z-axis
$\dot{r}$	$\dot{r}' = \frac{\dot{r}\ell^2}{U^2}$	Angular acceleration component relative to z-axis
U	$U' = 1$	Velocity of origin of body axis relative to fluid in feet per second.
v	$v' = \frac{v}{U}$	Component along y-axis of velocity of origin of body axes relative to fluid
$\dot{v}$	$\dot{v}' = \frac{\dot{v}\ell}{U^2}$	Component along y-axis of acceleration of origin of body axes relative to fluid

Symbol	Dimensionless Form	Definition
w	$w' = \frac{w}{U}$	Component along z-axis of velocity of origin of body axes relative to fluid
$\dot{w}$	$\dot{w}' = \frac{\dot{w}\ell}{U^2}$	Component along z-axis of acceleration of origin of body axes relative to fluid
X	$X' = \frac{X}{\frac{1}{2}\rho \ell^2 U^2}$	Hydrodynamic longitudinal force, positive forward
Y	$Y' = \frac{Y}{\frac{1}{2}\rho \ell^2 U^2}$	Hydrodynamic lateral force, positive starboard
Y_r	$Y_r' = \frac{Y_r}{\frac{1}{2}\rho \ell^3 U}$	Derivative of lateral force component with respect to angular velocity component r
$Y_{\dot{r}}$	$Y_{\dot{r}}' = \frac{Y_{\dot{r}}}{\frac{1}{2}\rho \ell^4}$	Derivative of lateral force component with respect to angular acceleration component $\dot{r}$
Y_v	$Y_v' = \frac{Y_v}{\frac{1}{2}\rho \ell^2 U}$	Derivative of lateral force component with respect to velocity component v
$Y_{\dot{v}}$	$Y_{\dot{v}}' = \frac{Y_{\dot{v}}}{\frac{1}{2}\rho \ell^3}$	Derivative of lateral force component with respect to acceleration component $\dot{v}$
Z	$Z' = \frac{Z}{\frac{1}{2}\rho \ell^2 U^2}$	Hydrodynamic normal force, positive downward
Z_q	$Z_q' = \frac{Z_q}{\frac{1}{2}\rho \ell^3 U}$	Derivative of normal force component with respect to angular velocity component q
$Z_{\dot{q}}$	$Z_{\dot{q}}' = \frac{Z_{\dot{q}}}{\frac{1}{2}\rho \ell^4}$	Derivative of normal force component with respect to angular acceleration component $\dot{q}$

Symbol	Dimensionless Form	Definition
Z_w	$Z_w' = \frac{Z_w}{\frac{1}{2}\rho \ell^2 U}$	Derivative of normal force component with respect to velocity component w
$Z_{\dot{w}}$	$Z_{\dot{w}}' = \frac{Z_{\dot{w}}}{\frac{1}{2}\rho \ell^3}$	Derivative of normal force component with respect to acceleration component $\dot{w}$
α		Angle of attack
β		Angle of drift
θ		Angle of pitch
ρ		Mass density of water
ψ		Angle of yaw
ω	$\omega' = \frac{\omega \ell}{U}$	Circular frequency of oscillation
ϕ_s		Phase angle between forward and aft struts
Subscripts		
in		In-phase component of force or moment
out		Out-of-phase or quadrature component of force or moment
1		Associated with forward strut
2		Associated with aft strut

NOTE: All derivatives with respect to angular quantities are given as "per radian."

INTRODUCTION

Pursuant to the Bureau of Ships Variable Depth Sonar (VDS) Systems Subproject S2720, Fleet Support Development Task 11310, the David Taylor Model Basin initiated an investigative program to determine the stability derivatives of the AN/SQA-13 (XN-1) VDS vehicle. To achieve this objective, a full-scale model of the SQA-13 vehicle was constructed and tests were conducted on the DTMB Planar-Motion-Mechanism (PMM) System [1,2].

The purpose of this report is to make the data immediately available to the Bureau of Ships to facilitate procurement of the Independent VDS System. A brief description of the model, test apparatus, and procedures are given and the results of the tests are presented in the form of non-dimensional hydrodynamic coefficients. A final report containing a complete analysis of the data will be issued in the near future.

DESCRIPTION OF VEHICLE

The SQA-13 (XN-1) vehicle tentatively proposed for the Independent VDS System is herein designated as the Scheme A Body. Figure 1 is a photograph of the prototype body and Figure 2 is a photograph of the model used for the experiments. The physical characteristics and dimensions for prototype and model are listed in Table 1. The horizontal stabilizing surfaces are located on opposite ends of a vertical stabilizing surface on the aft section of the body. The upper horizontal surface is set at a zero-degree angle of incidence; the lower horizontal surface is set at a 3.5-degree (leading edge down) angle of incidence. The prototype body was constructed of fiberglass with a cast aluminum upper dome. The model was constructed of mahogany with a fiberglass upper dome to permit access to the inside of the body.

[1] Gertler, M., "The DTMB Planar-Motion-Mechanism System," David Taylor Model Basin Paper for Symposium on Towing Tank Facilities, Instrumentation and Measuring Technique, Zagreb, Yugoslavia (Sept 1959).

[2] Goodman, A., "Experimental Techniques and Methods of Analysis Used in Submerged Body Research," David Taylor Model Basin Paper Prepared for the Third Symposium on Naval Hydromechanics, The Hague, Netherlands (Sept 1960).

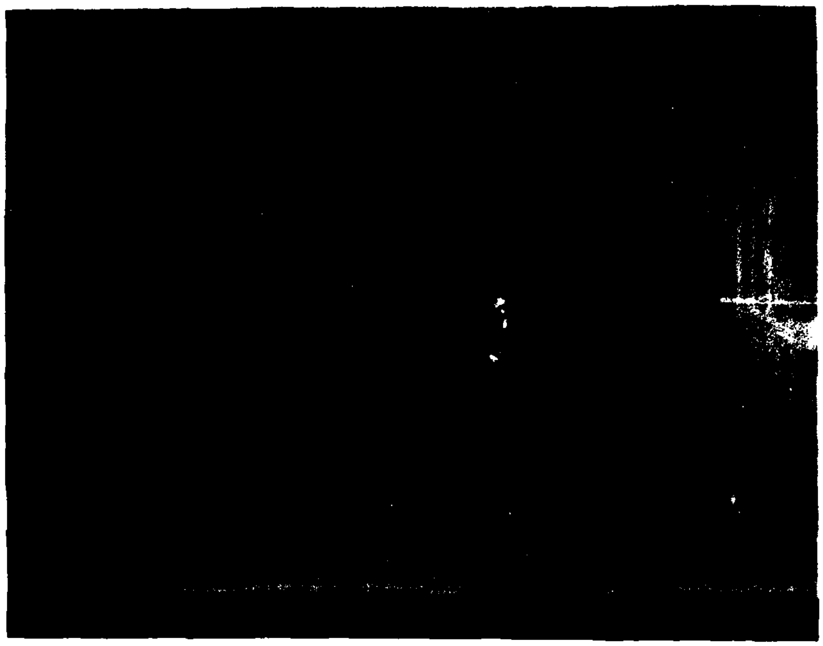

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Figure 1a - Side View

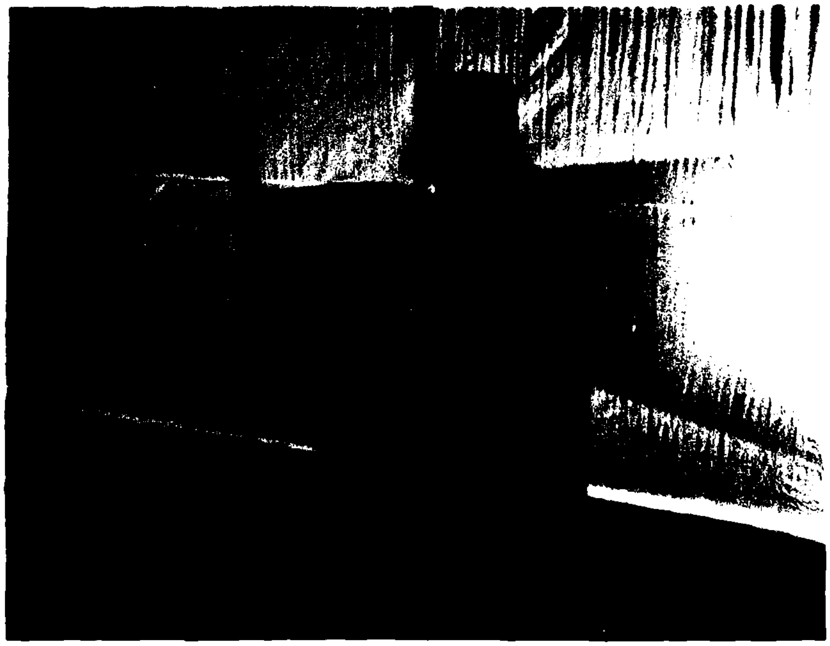

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Figure 1b - Oblique Front View

Figure 1 - Scheme A Body of the AN/SQA-13 Variable Depth Sonar System

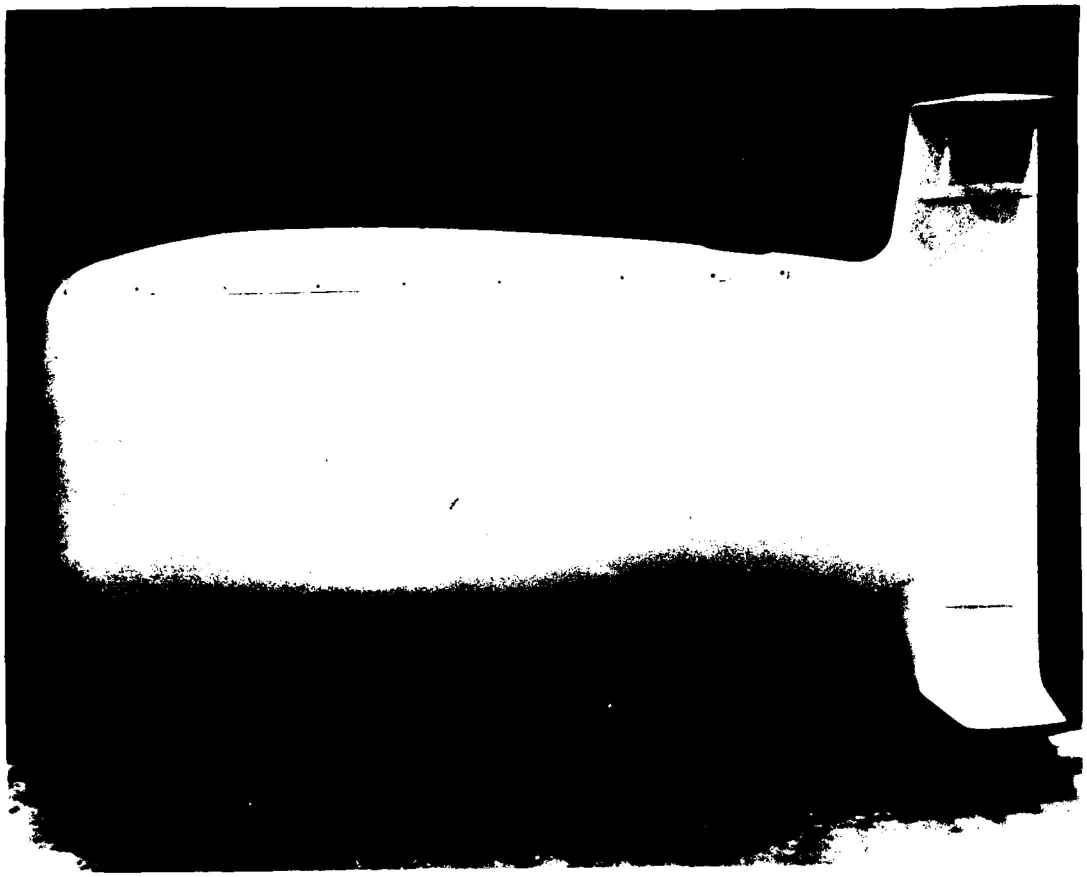

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Figure 2 - Model of the Scheme A Body

TABLE 1

PHYSICAL CHARACTERISTICS OF THE SCHEME A BODY

	Prototype	Model
Length overall, feet	8.12	8.12
Maximum body width, feet	2.17	2.17
Maximum body height, feet	4.04	4.04
Height of tail, feet	4.62	4.62
Longitudinal distance from nose to towpoint, feet	2.33	-
Longitudinal distance from nose to CG, feet	-	3.42
Longitudinal distance from nose to CB, feet	-	3.42
Height of CG above keel, feet	-	1.99
Height of CB above keel, feet	-	2.08
Total wetted surface area, square feet	80.0	80.0
Frontal area of body, square feet	7.14	7.14
Horizontal planform area of bare body, square feet	7.84	7.84
Planform area of vertical tail surface, square feet	5.54	5.54
Planform area of upper horizontal tail surface, square feet	1.50	1.50
Planform area of lower horizontal tail surface, square feet	2.0	2.0
Planform area of each vertical trim tab, square feet	0.22	-
Planform area of each horizontal trim tab, square feet	0.09	-
Volume, cubic feet	31.35	31.35
Displacement, pounds	-	1953
Weight in fresh water, pounds	2975	-
Weight in standard sea water, pounds	2951	-
Weight in air, pounds	3825	-
Static trim angle in water, degrees	0	-

NOTE: Standard sea water conditions are 45 degrees N. Latitude, 3.5 percent salinity and 59 degrees F. Planform area of the vertical tail surface is defined by projecting the leading edge of the upper and lower portions to the centerline of the body.

TEST APPARATUS AND PROCEDURES

The test apparatus consisted of the PMM System mounted on Carriage 2 of the Deep Water Basin. The PMM system is a device that measures forces and moments in six degrees of freedom while imparting pitching, heaving, or rolling motions to the model and records the data in digital form.

In the tests to obtain the stability measurements in the vertical plane, the model was ballasted to approximately neutral buoyancy and attached to the two PMM struts spaced 4.5 feet apart. A point located on the longitudinal centerline of the body 3.5 feet from the nose and midway between the support points was used as a reference for the stability derivatives. The tests were conducted in the following three phases:

1. Resistance - These tests were conducted over a speed range from 0 to 12 knots with the body held at zero angle of attack to the stream. The axial force was measured and recorded.

2. Static Stability - These tests were conducted at speeds of 6 and 9 knots. At 6 knots the angle of attack of the model was varied between ±15 degrees; at 9 knots the angle of attack was varied between ±8 degrees because forces approached limits of the gages. Tare readings for the measurements were taken at 0 speed by tilting the body at incremental pitch angles between ±15 degrees.

3. Dynamic Stability - These tests were conducted at speeds of 0, 5, 7, and 9 knots. The body was heaved and pitched at frequencies of 1.112, 2.220, and 3.324 radians per second. The forces were measured for each speed and frequency.

In the tests to obtain the stability measurements in the horizontal plane, the body was rotated 90 degrees (port side down), reballasted, and attached to the struts using the same spacing. The same three types of tests were then conducted for the measurements in the horizontal plane.

REDUCTION AND PRESENTATION OF DATA

The curves of nondimensional force or moment coefficient as a function of the appropriate parameter for the Scheme A body are presented in

Figures 3 through 10. The stability derivatives determined from the static and dynamic tests are summarized in Table 2. The values listed in Table 2 for the static stability derivatives were determined from the slopes (through zero) of the curves of force or moment versus body angle. The rotary and acceleration derivatives were obtained by substituting values from the plots of in-phase or quadrature (out) force components as a function of the velocity and acceleration parameters in the reduction equations given in References 1 and 2. Attention is called to the fact that the reference for the derivatives is on the longitudinal centerline of the body 3.5 feet aft of the nose.

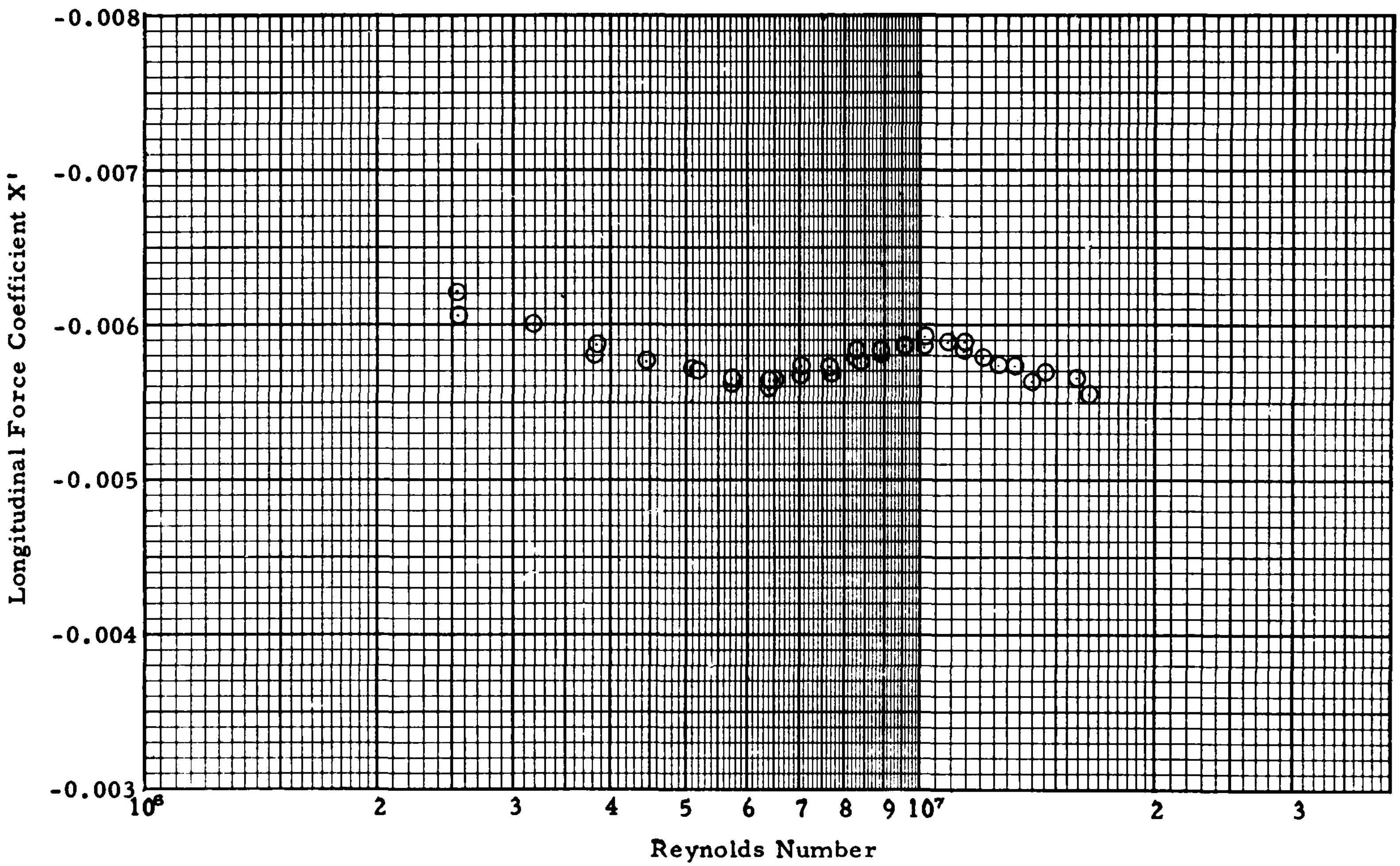

Figure 3 - Longitudinal Force Coefficient at a Zero Pitch Angle as a Function of Reynolds Number Based on Length

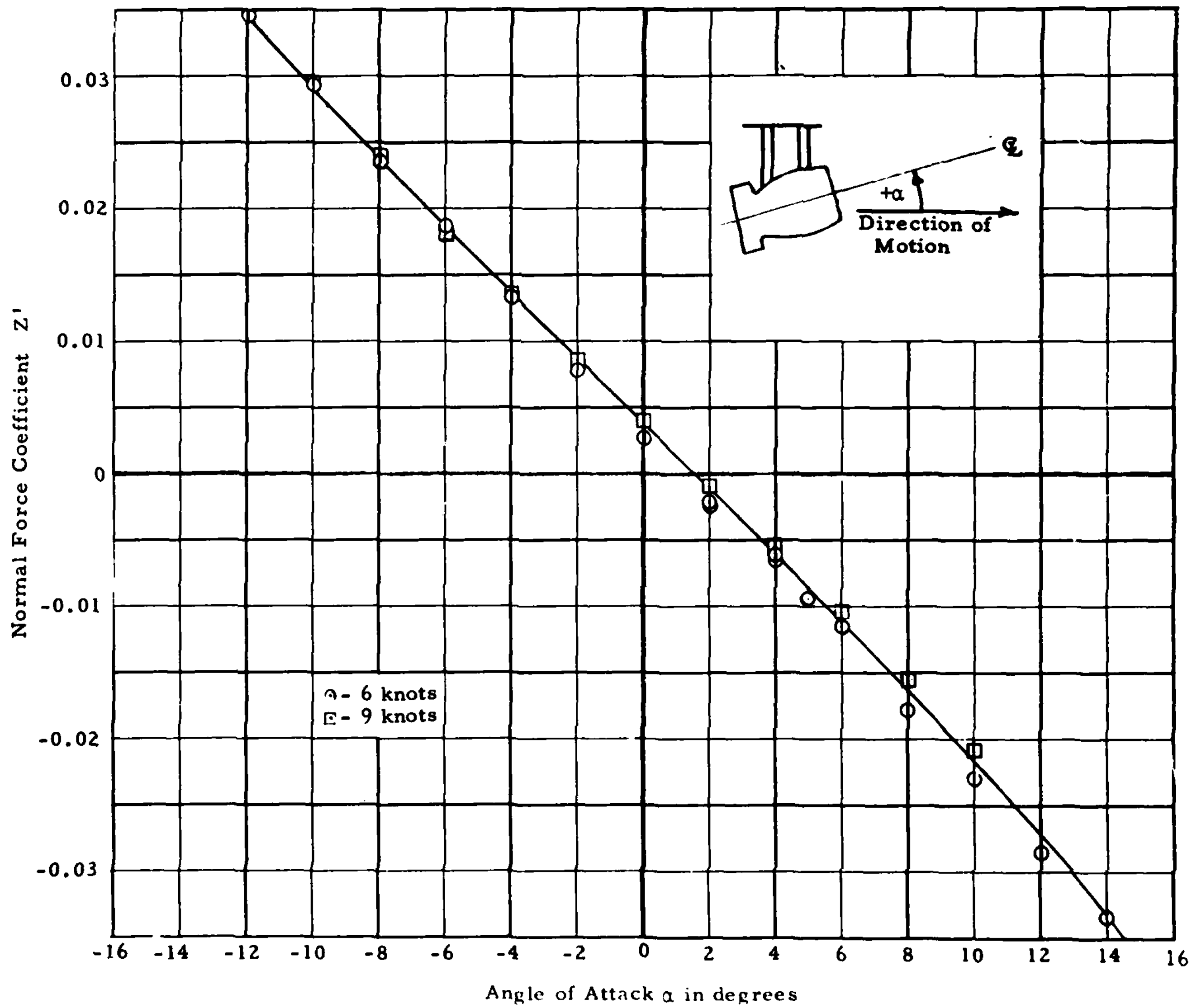

Figure 4 - Normal Force Coefficient as a Function of Angle of Attack

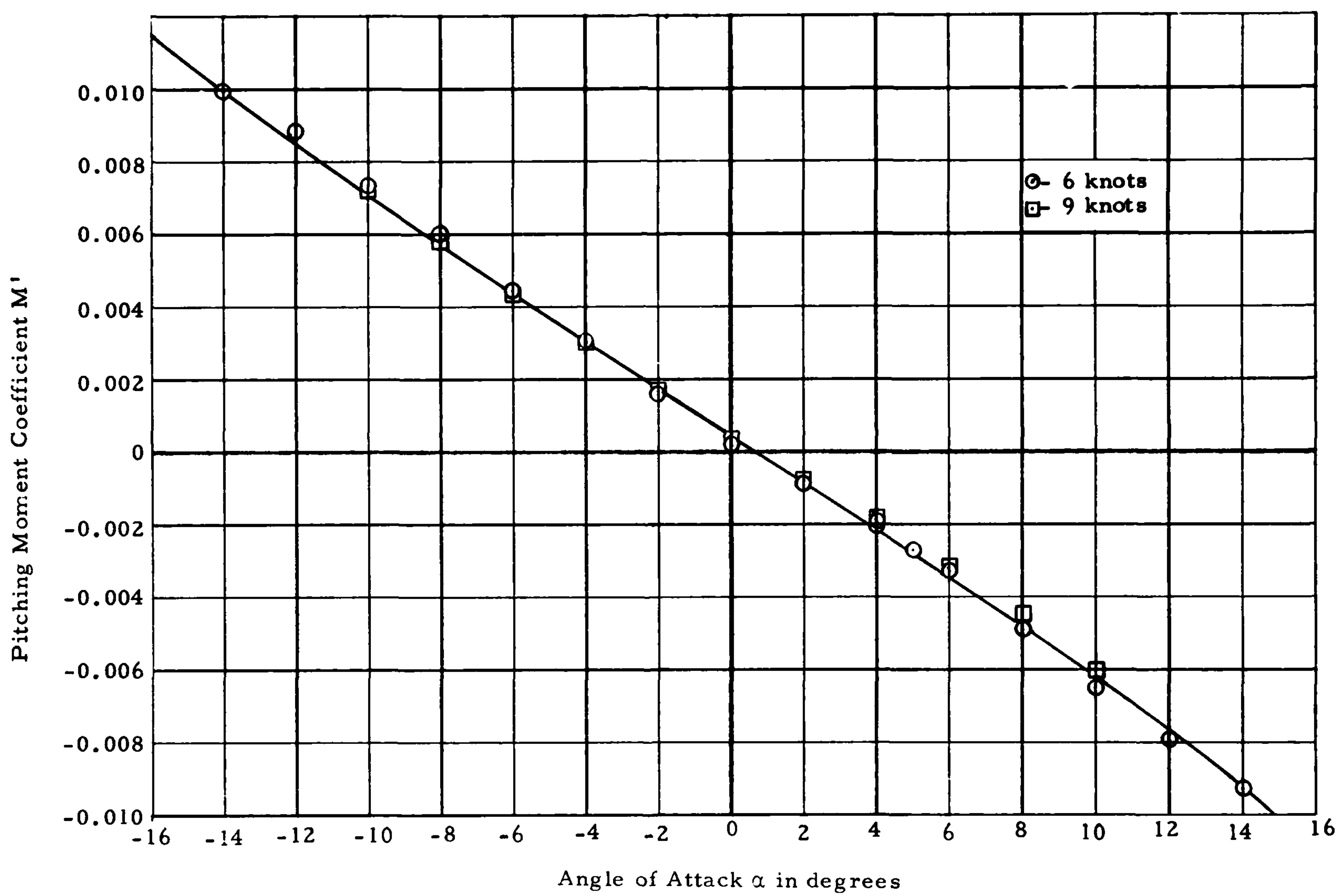

Figure 5 - Pitching Moment Coefficient as a Function of Angle of Attack

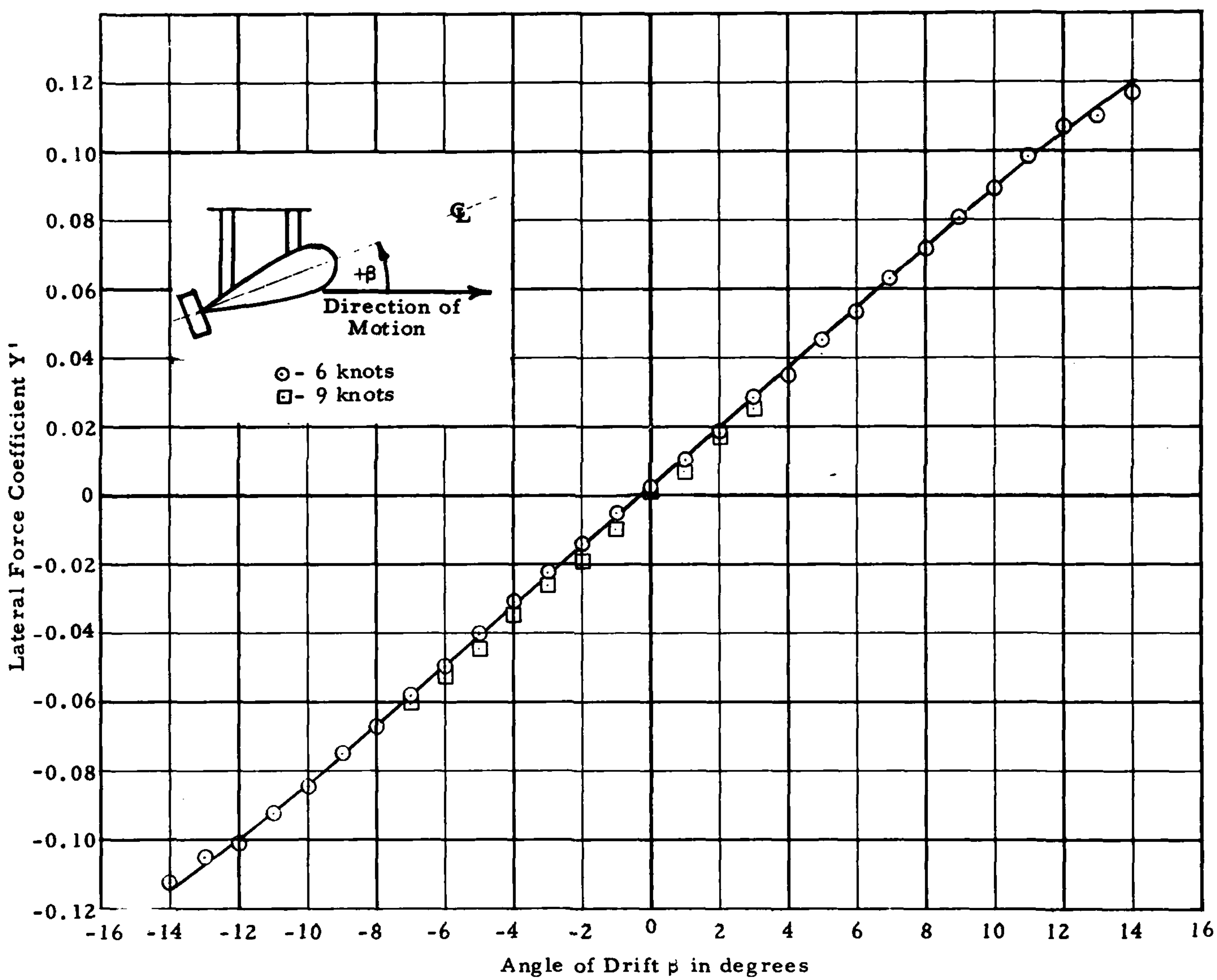

Figure 6 - Lateral Force Coefficient as a Function of Angle of Drift

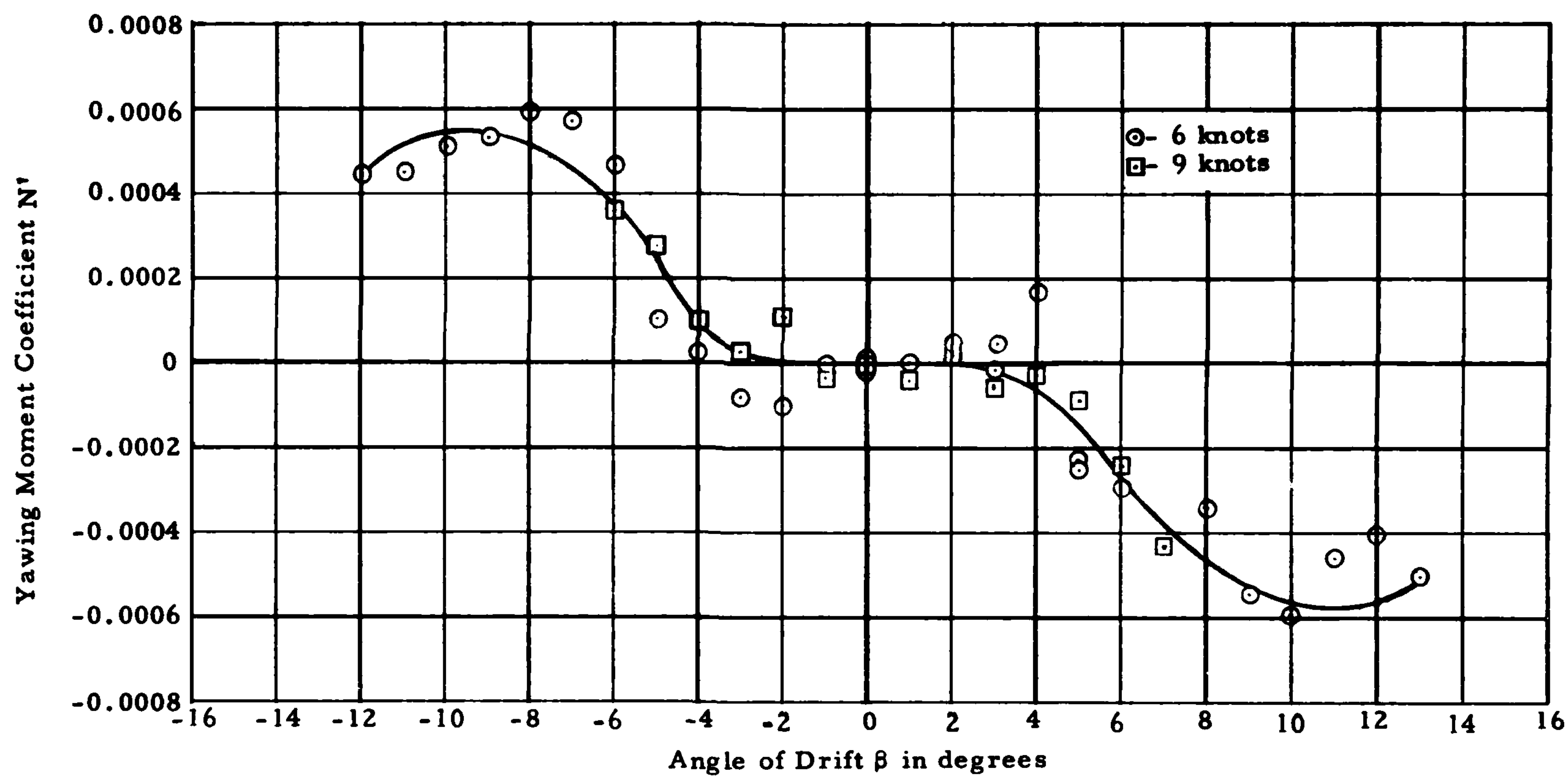

Figure 7 - Yawing Moment Coefficient as a Function of Angle of Drift

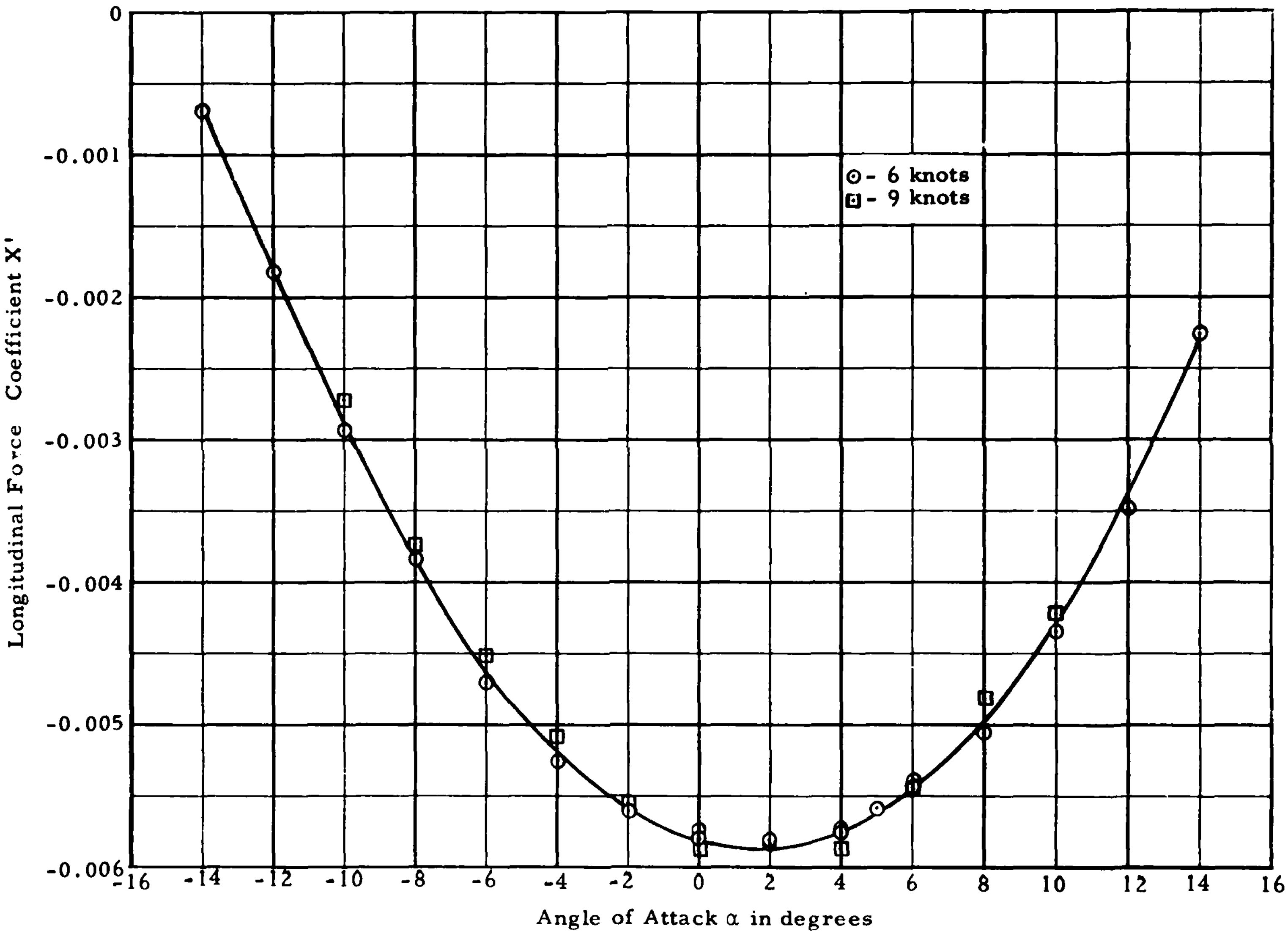

Figure 8 - Longitudinal Force Coefficient as a Function of Angle of Attack

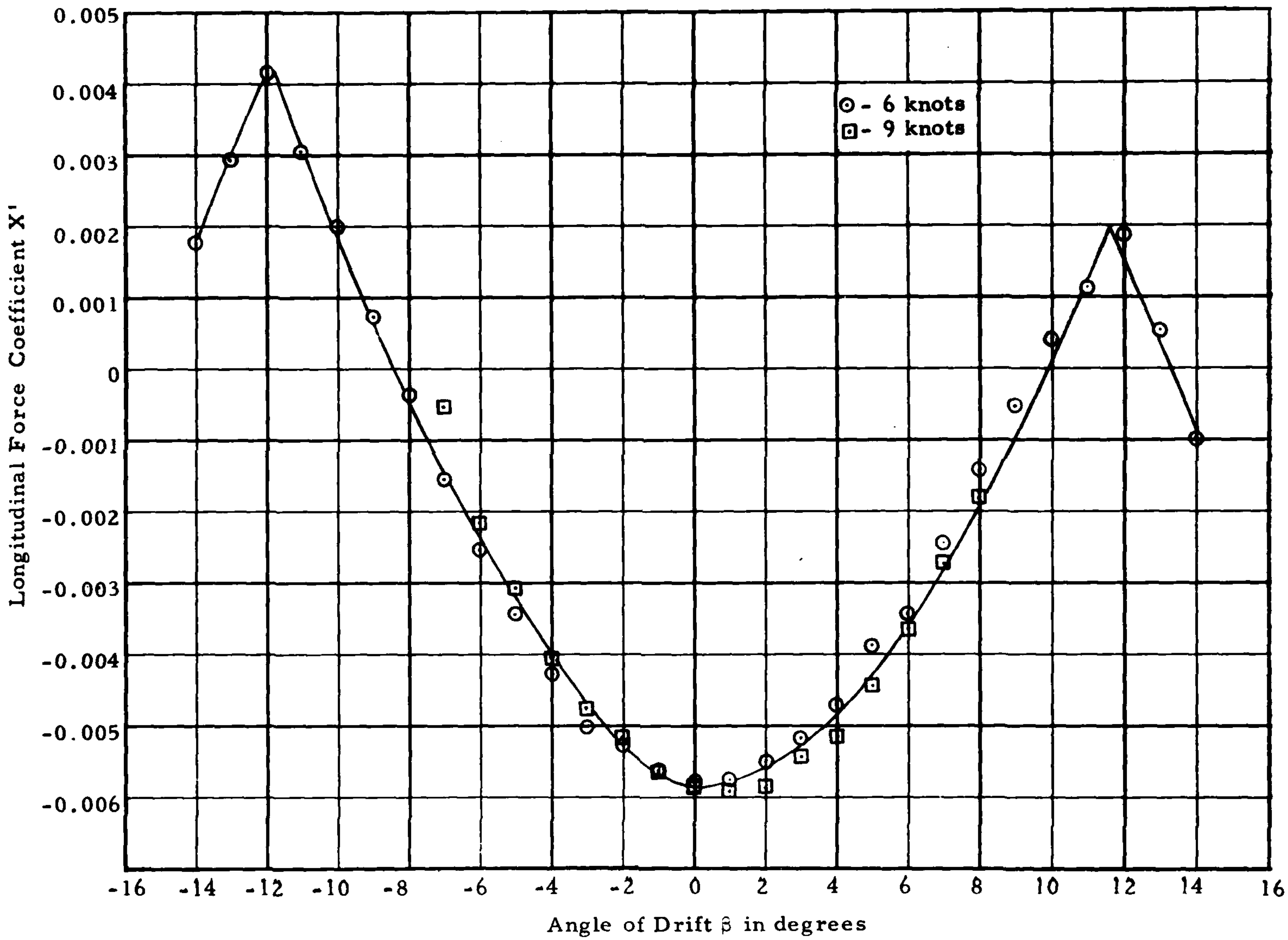

Figure 9 - Longitudinal Force Coefficient as a Function of Angle of Drift

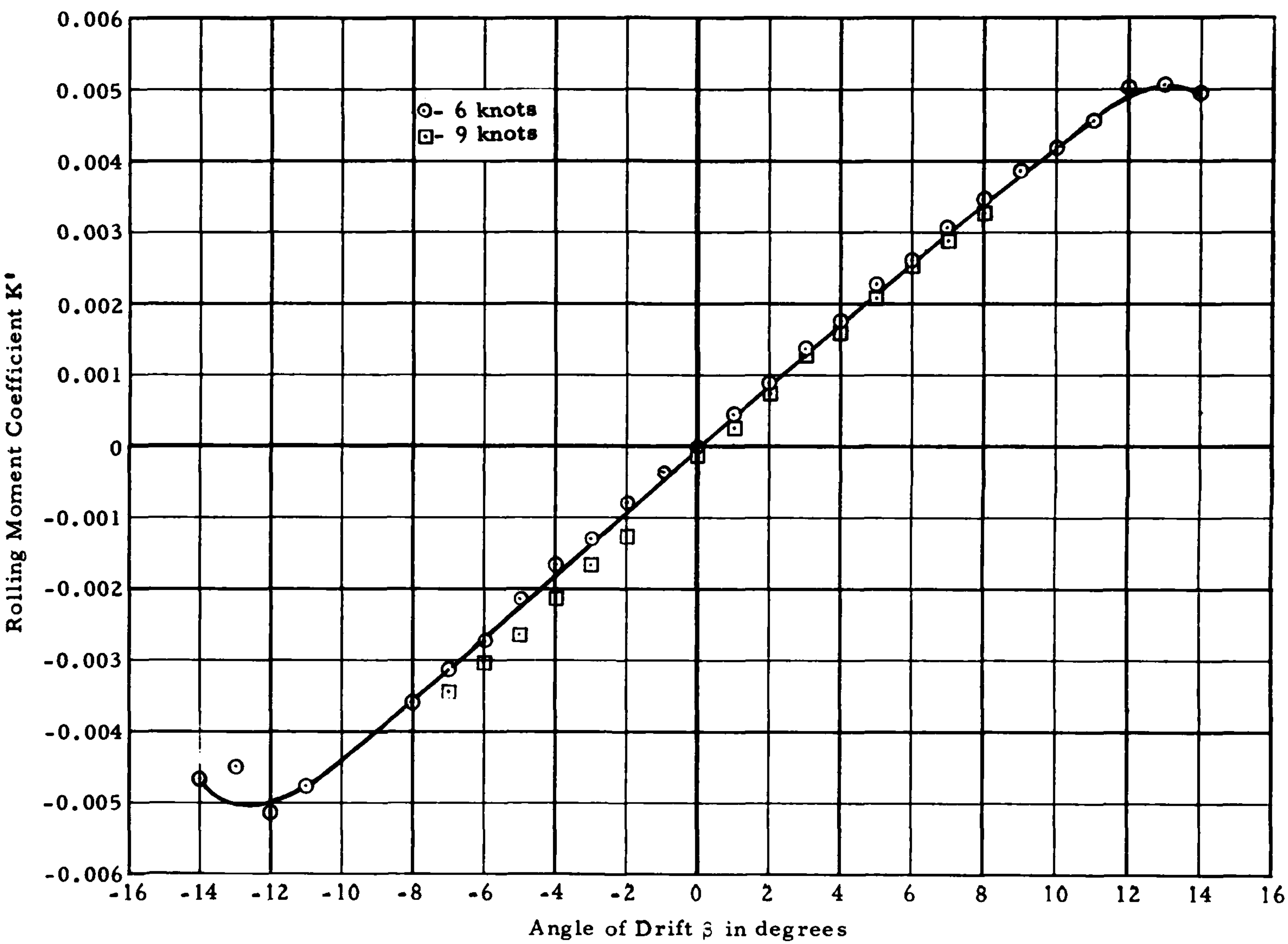

Figure 10 - Rolling Moment Coefficient as a Function of Angle of Drift

TABLE 2

Nondimensional Values of Stability Derivatives

Vertical Plane	Horizontal Plane
$Z_w' = -0.14268$	$Y_v' = -0.49278$
$M_w' = -0.03724$	$N_v' = 0$
$Z_{\dot{w}}' = -0.06860$	$Y_{\dot{v}}' = -0.22140$
$M_{\dot{w}}' = 0.00585$	$N_{\dot{v}}' = -0.00187$
$Z_{\dot{q}}' = 0.00483$	$Y_{\dot{r}}' = 0.01348$
$M_{\dot{q}}' = -0.00303$	$N_{\dot{r}}' = -0.01417$
$Z_q' = -0.02690$	$Y_r' = 0.13660$
$M_q' = -0.04570$	$N_r' = -0.08020$
$m_a' = 0.11790$	$I_{zm}' = 0.00552$
$I_{ym}' = 0.00504$	$K_v = -0.02550$
	$K_{\dot{v}} = -0.04250$
	$K_r = 0.07900$
	$K_{\dot{r}} = 0.01591$

NOTE: All derivatives are referred to a point 3.5 feet aft of the nose on the longitudinal centerline of the body.